Nanowire Templated Lateral Epitaxial Growth of High Quality GaN

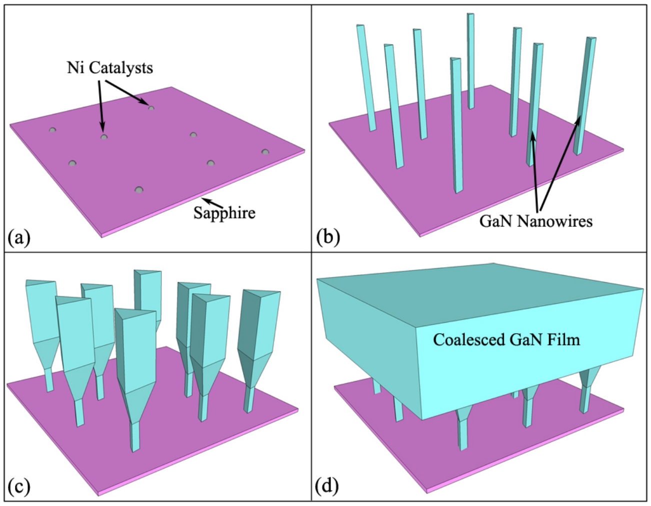

Figure 1: NTLEG growth process. (a) catalyst nucleation; (b) vertically-aligned nanowire growth; (c) lateral growth; and (d) full coalescence of the upper section into a suspended GaN film that is bridged to the substrate by the nanowires.

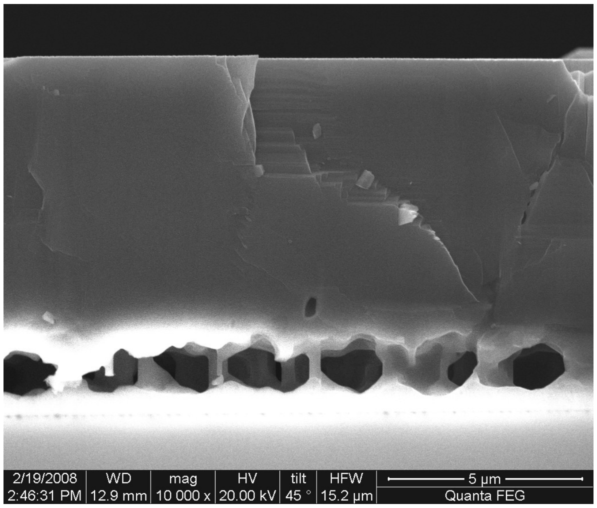

Figure 2: Cross-section scanning electron micrograph showing a fully-coalesced GaN film bridged to the sapphire substrate via vertically-aligned GaN nanowires.

New technique may improve performance of energy-saving solid-state lighting devices

For more information:

Technical Contact:
George T. Wang
505-284-9212
gtwang@sandia.gov

Science Matters Contact:
Alan Burns
505-844-9642
aburns@sandia.gov

Artificial lighting consumes about 20 percent of electricity in the U.S., due in large part to the poor energy efficiency of incandescent bulbs. A potential solution resulting in huge future energy savings is found in the much more efficient solid-state lighting (SSL). At the heart of SSL is the light-emitting diode (LED), a device which typically consists of a sandwich of gallium nitride (GaN)-based semiconductor layers that emits visible light when electrically driven. Most LEDs are grown on crystalline substrates such as sapphire, because bulk GaN crystals are difficult to grow. Unfortunately, the large lattice mismatch, or difference in atomic spacing, between GaN and the sapphire results in the formation of very high densities (~1 billion/cm^2) of extended defects (threading dislocations) in the GaN layers. These defects significantly degrade the efficiencies and lifetimes of visible LEDs, and thus hinder the development of high performance SSL.

At Sandia, researchers have developed an innovative and inexpensive technique to produce high-quality, relatively defect-free GaN on sapphire substrates by employing aligned arrays of single-crystalline GaN nanowires as templates (Reference 1). In this technique, called nanowire-templated lateral epitaxial growth (NTLEG) and illustrated in Figure 1, a vertical and dense array of aligned GaN nanowires is first grown on sapphire by a metal-catalyzed metal-organic chemical vapor deposition process. The growth conditions are then changed *in-situ* to quench axial nanowire growth and nucleate lateral GaN film growth at the upper part of the nanowire template until a coalesced film is formed. This continuous suspended GaN film is bridged to the substrate by the GaN nanowire array, as shown in a cross-section electron micrograph (Figure 2).

The GaN nanowires (Figure 3) have a number of unique properties that lead to the reduction in defects in the GaN films grown by this technique. Because of their small dimensions (typically less than 100 nm diameter) and 1D-like morphology, the nanowires can relax laterally to relieve the strain caused by growth on lattice mismatched substrates. Since strain is the primary cause of defects, this results in GaN nanowires that are free of threading dislocations, providing a high-quality template for GaN film growth. Additionally, this property allows the nanowires to serve as a strain-compliant bridge from the coalesced GaN film to the lattice-mismatched substrate. Finite element models (Figure 4) show that the strain caused by the lattice mismatch of GaN and sapphire decays exponentially from the nanowire-sapphire interface, and is dissipated away from the suspended GaN film. Structural analysis of preliminary GaN films (Figure 5) shows an approximate fifty times reduction in threading dislocation density compared to films of the same crystal orientation grown by conventional buffer-layer techniques; further optimization of the technique is expected to result in additional gains. In addition to better LEDs for more efficient SSL, this technology could also lead to improvements in other GaN-based technologies including blue laser diodes (e.g., Blu-Ray) and high-speed, high-power electronics.

Reference

1. Q. Li, Y. Lin, J. R. Creighton, J. J. Figiel, G. T. Wang, "Nanowire-templated lateral epitaxial growth of low-dislocation density nonpolar a-plane GaN on r-plane sapphire", *Adv. Mater.* **2009**, *21*, 2416.

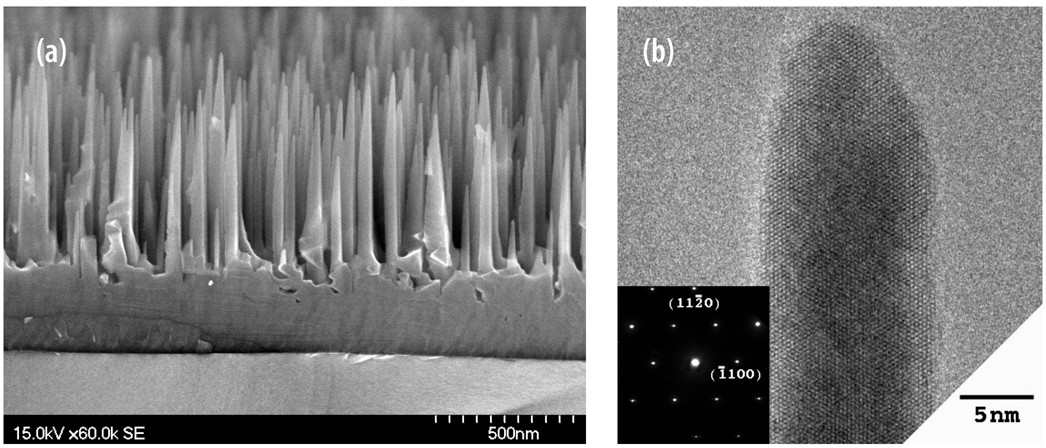

Figure 3: (a) Scanning electron micrograph showing highly-aligned and dense GaN nanowire growth on sapphire; (b) transmission electron micrograph and diffraction pattern (insert) showing single-crystalline, dislocation-free structure of a GaN nanowire.

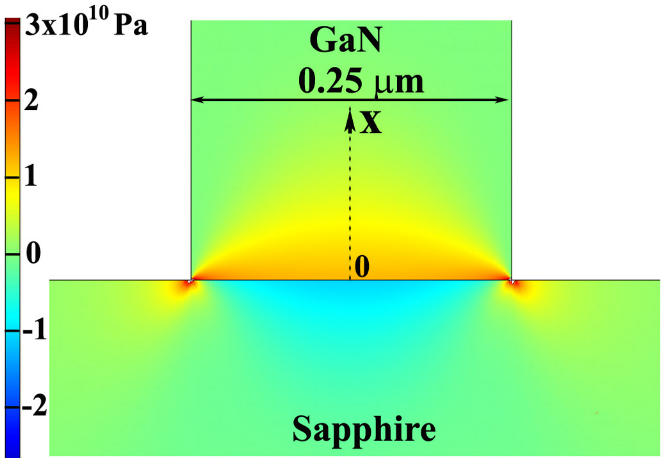

Figure 4: Finite element analysis of lattice mismatch strain distribution in a 0.25-μm-wide GaN nanowire on bulk sapphire substrate, showing rapid strain relaxation in the nanowire away from the interface.

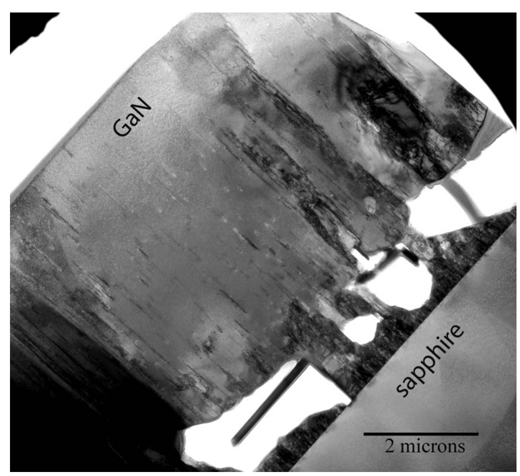

Figure 5: Cross-section transmission electron micrograph showing a large reduction in threading dislocations (denoted by dark striations) near the top of the suspended GaN film compared to the highly-defective, high-strain region near the nanowire/sapphire interface.

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